LMSS Final Report and Project Summary

Covering the contract period January 1989 to August 1989

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1. INTRODUCTION

The Virginia Tech Satellite Communications Group has participated in the LMSS program through JPL sponsorship since 1985. Our involvement has mainly been in modeling and simulation of propagation characteristics and effects. Models developed to predict cummulative fade distributions for fading LMSS signals include LMSSMOD and the Simple Models which approximate LMSSMOD. We have also developed models to predict the mean and standard deviation of signal attenuation through roadside vegetation, namely the Average Path Model. In the area of simulation, our efforts have centered around the development of a software simulator that uses data bases derived from experimental data to generate simulated data with arbitrary statistical behavior. This work has progressed to the development of an integrated analysis and simulation package, **LIPS**. The basic theory and results for the models and simulator have been documented in reports and papers previously submitted. These are listed in Section 3.4.

This final report serves to briefly summerize all LMSS activities and give details of this year's efforts.

2. MONTHLY REPORT FOR JUNE THROUGH AUGUST

During the month of June we prepared and presented two papers at the 1989 Antennas and Propagation Society International Symposium and URSI Radio Science Meeting/NAPEX XIII meetings in San Jose, CA. The paper "Modeling and simulating secondary fading statistics of mobile satellite signals" by R. M. Barts and W. L. Stutzman was presented during URSI Session 81 of the APS/URSI Symposium. During the NAPEX XIII meeting, the paper "LMSS modeling status report" by W. L. Stutzman and R. M. Barts was presented. These papers outlined the results of our autocorrelation and fading spectra studies and the improvements these suggested to our data processing used to create data bases used by the propagation simulator. Both papers were well received.

It was also during June that the development of the software used to create the propagation simulator data bases and analyze simulated and measured data evolved into a unified software system that we now refer to as the **L**MSS **I**ntegrated **P**ropagation **S**oftware, or by its acronym, **LIPS**. **LIPS** is a simulation and analysis system for LMSS propagation that runs on a PC that operates in an integrated software environment. It consists of several different programs to perform the simulation and analysis functions managed by a program manager that allows the user to operate the system through the use of pull down menus. The **LIPS** system makes it easier for the user to interact with the programs and provides common access to groups of programs that are used in conjunction with one another.

The **LIPS** software has three main menus which divide the processing and analysis of LMSS propagation data into separate, common functions: Simulation, Raw Data Analysis, and Data Base Generation. The first menu, Simulation, allows the user to run the propagation simulator, analyze the statistics of the simulated data, and display the statistics graphically on screen. The second menu, Raw Data Analysis, contains functions that allow the user to analyze the statistical behavior of the experimental data recorded by Vogel and Goldhirsh, and display the statistics graphically on screen. The third menu, Data Base Generation, contains all the functions needed to process experimental data to create Rayleigh and lognormal data bases for use by the propagation simulator.

The software modules in **LIPS** are modified versions of the software developed on the Harris H800 computer for our LMSS research. All of the programs are written in Fortran 77 with the exception of the program manager, DOS utilities, and graphics utilities which are written in C.

During July we completed the conversion of the software in the **LIPS** package from the Harris computer to the PC and tested it for proper operation and compatibility. The modifications to the data processing for generating the data bases were also implemented. These consisted, in part, of implementing FIR filters in the averaging processing to generate a better estimate of the lognormal (shadowed) component of the signal. The new software allows the user to custom design the FIR filter, choosing from four different filter types: rectangular, Hanning, Hamming, and Blackman filters. The choice of filter and the filter characteristics (cutoff frequency and stopband frequency) should be chosen after an examination of the fading spectrum of the data being processed. A possible future addition to the **LIPS** package would be an FFT and graphing routine to allow spectral analysis of the experimental data. Due to time constraints we did not try to implement this in the package.

Documentation of the **LIPS** software package began in July and continued into August. The documentation package [Ref 2 of Sec. 3.4.4] consists of a users guide to **LIPS** that details how to use the system with step by step instructions for running each program. Also included are program descriptions and flow charts for each module. A draft of the users guide is included with this report. Additionally, each module's source code module has been extensively documented and commented to facilitate future modifications.

In parallel with our development and testing of the **LIPS** software package, we have been working on journal and conference papers to publicize the results of our work. A conference paper submitted to the Globecom conference was rejected in July, but was re-edited and submitted to the IEEE Vehicular Technology Conference scheduled for next May. The conferences that we had previously submitted to were not directly concerned with mobile or satellite communications, thus our paper's subject was a fringe topic. The Vehicular Technology conference has mobile satellite communications listed as a topic. The VT community is also a group to which we have not previously presented our work. Work continues on our papers for publication in refereed and trade journals as well. Included with this report is an outline for each of the papers that is in production.

With this monthly report we end the contractual work on LMSS propagation modeling. The **LIPS** software package and its documentation and copies of the technical papers produced from this work constitute the deliverables. The software and user's guide are attached. The technical papers will be forwarded upon their completion.

3. CUMMULATIVE SUMMARY OF ACCOMPLISHMENTS

This section details the cummulative summary of accomplishments in LMSS research during the contract period January 1989 to August 1989.

3.1 Autocorrelation and Spectrum Studies

Our study of the fading signal autocorrelation and spectrum was motivated by the need to improve the secondary statistical performance of the software propagation simulator. The signal autocorrelation is related to the secondary, or conditional, statistical behavior of the signal. By examining the autocorrelation of experimental data, we gathered references for comparision with the simulator. Our analysis also revealed some interesting features about the experimental data that we were working with. The helicopter and MARECS data displayed a rapid decorrelation, while the balloon data displayed a slow decorrelation that also contained some cross correlation between the in-phase and quadrature signal components. The differences between the data was partially explained by differences in vehicle speeds during the measurements, the vehicle was moving much slower for the balloon measurements.

The autocorrelation of the fading signals were also used to obtain the fading signal spectrum since the two are related via the Fourier transform. Using the autocorrelation to derive the fading spectrum has several advantages over a direct Fourier transform of the sampled data. The autocorrelation process acts as a noise filter because wideband gaussian noise is decorrelated. Spectra averaging of consecutive records of data is a simple task using autocorrelation functions. The result is a spectrum whose dominant features and characteristics are more easily recognizable.

The spectrum studies were used in the effort to modify the data processing used to derive the data bases used in the propagation simulator. By observing the spectrum of the experimental data, the appropriate filter characteristics can be chosen. A properly designed filter will improve the estimates for the lognormal and Rayleigh signal components being extracted from the experimental data. For example, the power spectrum for a sample file of helicopter data might indicate a main lobe peak on the order of 4 Hz wide with a multipath spectrum that extended out to 100 Hz. The main lobe contains the lognormal estimate data and the multipath spectrum contains the Rayleigh estimate data. An appropriately designed filter for this data might have a cutoff frequency of 3 Hz and a stopband frequency of 20 Hz. The choice of the filter characteristics and filter type are user selectable in the **LIPS** package and would depend on the filter length and stopband attenuation desired.

In addition, the study of fading spectra was used to compare various multipath models to experimentally measured data. The Jakes multipath model and multipath simulations by Campbell were examined. The Jakes multipath model showed good agreement with balloon data which had very light shadowing, while Campbell's simulations showed more agreement with the helicopter and MARECS data. An examination of the assumptions of the Jakes model revealed several assumptions that may not be valid in heavily wooded regions. The first of these is that the scatterers are in the far field. This would not be correct along a road with trees clsoe to the roadway. The second assumption was that the angular distribution of the scatterers was uniform. A straight road may have trees along both sides, but the directions directly in front of and behind the vehicle will generally be free of vegetation, thus the angular distribution of vegetation, and thus scatterers, will not be uniform. The simulations by Campbell accounts for these assumptions. The result appears to be a more accurate multipath model for heavy shadowing.

3.2 Simulator Improvements/Software Package

As detailed in Sections 2 and 3.1, several modifications have been made to the software propagation simulator. The first major modification involved the creation of a program manager to run the various programs and to provide the user with an integrated operating environment for using the simulator and supporting software modules. These modifications are detailed in Section 1.

The second major modification involved the implementation of FIR filters in the data processing used to generate estimates of the lognormal and Rayleigh signal components in the experimental data.

These changes to the data processing allow the creation of more accurate data bases used in the propagation simulator. These changes are detailed in Section 3.1.

3.3 Secondary Statistics

We investigated analytical models that exist for predicting secondary (or conditional) statistics. In particular we examined the mathematical development of expressions for secondary statistics in Jakes' book **Microwave Mobile Communications.** In this model, a theoretical model for the multipath spectrum is used to derive an expression for the level crossing rate (LCR) of the fading signal. Our study of the multipath sprectrum had already shown that the measured multipath spectrum did not agree with Jakes' theoretical multipath model. However, the LCR expression depended only on the moments of the mutlipath spectrum, not the spectrum itself. Our examination of Campbell's multipath simulations indicate that they produce spectra that show better agreement with measured spectra than the Jakes' theoretical model. We believe that using Campbell's simulated multipath spectrum in the mathematical framework from Jakes, more accurate expressions for the LCR may be attainable. The difficulty is in evaluating the moments of the multipath spectrum with Campbell's simulated spectrum, which will require numerical integration using simulated spectra generated by Campbell. Because of this difficulty, and time constraints, we were not able to reach any conclusions on this approach to modeling secondary statistics, but believe that it is worth pursuing.

3.4 Publications

This section is a cumulative list of all papers and publications by the Satellite Communications Group that have been produced or are being produced as the result of our research in LMSS propagation.

3.4.1 Technical Papers Presented

1. W. T. Smith and W. L. Stutzman, "Propagation modeling for land mobile satellite communications," URSI Radio Science Meeting (Philadelphia, PA), June 1986.

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2. R. G. Schmier, C. W. Bostian, W. L. Stutzman, and T. Pratt, "Fade durations in satellite-path mobile radio propagation," Proceedings of URSI Commission F Symposium on Wave Propagation: Remote Sensing and Communications (Durham, NH), pp. 8.6.1 - 8.6.3, July 1986.

3. R. G. Schmier, W. L. Stutzman, M. Barts, and C. W. Bostian, "The duration of fades in satellite to land mobile propagation," URSI Radio Science Meeting (Boulder, CO), January 1987.

4. R. M. Barts, W. L. Stutzman, W. T. Smith, R. S. Schmier, and C. W. Bostian, "Land mobile satellite propagation modeling," 1987 IEEE Antennas and Propagation Society International Symposium Digest (Blacksburg, VA), June 1987.

5. R. G. Schmier and C. W. Bostian, "Fade durations in satellite-path mobile radio propagation," IEEE Transactions on Vehicular Technology, November 1987.

6. W. L. Stutzman, editor, "Mobile satellite propagation measurements and modeling: A review of results for systems engineers," Proceedings of the Mobile Satellite Conference (Pasadena, CA), May 1988.

7. R. M. Barts and W. L. Stutzman, "Propagation modeling for land mobile satellite systems," Proceedings of the Mobile Satellite Conference (Pasadena, CA), May 1988.

8. R. M. Barts and W. L. Stutzman, "Statistical propagation modeling of signal fadin on land mobile satellite systems," URSI Radio Science Meeting (Syracuse, NY), June 1988.

9. R. M. Barts and W. L. Stutzman, "Modeling and simulating secondary fadeing statistics of mobile satellite signals," URSI Radio Science Meeting (San Jose, CA), June 1989.

3.4.2 Technical Reports Issued

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1. W. S. Bradley and W. L. Stutzman, Propagation Modeling for Land Mobile Satellite Communications, Virginia Tech Report EE SATCOM 85-3, August 1985.

2. W. T. Smith and W. L. Stutzman, Statistical Modeling for Land Mobile Satellite Communications, Virginia Tech Report EE SATCOM 86-3, August 1986.

3. R. G. Schmier and C. W. Bostian, Fade Durations in Satellite-path Mobile Radio Propagation, Virginia Tech Report EE SATCOM 86-5, December 1986.

4. Annual Report Volume 1: Land Mobile Satellite Systems, Virginia Tech Report EE SATCOM 88-4, September 1988.

5. R. M. Barts and W. L. Stutzman, Statistical Modeling and Simulation of Mobile Satellite Propagation, Virginia Tech Report EE SATCOM 88-5, August 1988. (Appendix 1 to Volume 1: Land Mobile Satellite Systems of the 1988 Annual Report, Virginia Tech Report EE SATCOM 88-4)

3.4.3 Technical Papers to be Completed

1. R. M. Barts and W. L. Stutzman, "Modeling and simulation of land mobile satellite propagation effects," IEEE Transactions on Antennas and Propagation.

2. R. M. Barts, J. Kim, T. Pratt, W. L. Stutzman and C. W. Bostian, "Mobile satellite system performance through simulation," Vehicular Technology Conference (Orlando, FL), May 1990.

3. J. Kim and T. Pratt, "Simulation of the mobile satellite channel," IEEE Transactions on Communications.

6. J. Kim, R. Barts, T. Pratt, W. Stutzman, and C. Bostian, "Simulation of mobile satellite communications performance," MSAT-X Quarterly.

3.4.4 Software

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1. LMSSMOD

Documented in Reference 2 of Section 3.4.2

2. **LIPS**

Documented in User Guide to LMSS Integrated Propagation Software: **LIPS**, Version 1.0, August, 1989 (attached)